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REAL TIME FERROGRAPH DEVELOPMENT.(U)
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LEVEL II

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12

FINAL REPORT
80015

CONTRACT #N00140-76-C-0713

NAVAL AIR PROPULSION CENTER
P.O. Box 7176
TRENTON, NEW JERSEY
08628

DEVELOPMENT OF REAL TIME FERROGRAPH

E. R. Bowen

November 1979

FOXBORO

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

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Unlimited

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ferrography, Wear, Condition Monitoring, Real Time Monitoring.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the development of an on-board (aircraft) instrument to monitor the level of wear debris in the engine lube system. A completed instrument was delivered to the Naval Air Propulsion Center.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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ACKNOWLEDGMENTS

Foxboro Analytical wishes to acknowledge the foresight and support of the Naval Air Propulsion Center in funding this effort. In particular, the comments and advice of Richard Oberndorfer and Rick Lazerick were greatly appreciated.

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LIST OF FIGURES

1.0 INTRODUCTION

The intent of this contract was to develop an instrument capable of measuring the concentration of ferromagnetic wear debris in the lubricant of a jet engine. The instrument was to be an on-line device that would operate satisfactorily in an airborne environment..

A previous contract (#N00140-73-C-1065) had already demonstrated the test cell feasibility. However, it was felt that difficulties might be encountered when utilizing the original debris sensing technique (optical) in a truly operational environment. Difficulties expected were high ambient temperatures (rather than high oil temperature) and second phase air entrainment in the oil. The development was thus broken into two clearly identifiable parts. Firstly, the development of a satisfactory debris sensor; secondly, the configuration and assembly of one system suitable for airborne evaluation.

The following sections will discuss the effort expended in order to achieve these goals.

2.0 DEBRIS SENSOR DEVELOPMENT

As mentioned in the Introduction, potential difficulties with the optical sensing technique necessitated the investigation of alternative methods. Those investigated fell into the following categories:

Refined Optical	(2.1)
Resistive	(2.2)
Inductive	(2.3)
Hall Effect	(2.4)
Capacitive	(2.5)

2.1 Refined Optical

This effort was devoted to evaluating the possibility of improving the optical sensing method to eliminate its sensitivity to ambient temperature and second phase gases in the oil.

Thermoelectric devices are commercially available that will generate a differential temperature of $65^{o}C$. Since opteo-electronic devices (photodiodes, photoresistors, etc.) have a maximum operating temperature around $85^{o}C$, it is feasible to thermally protect the device to the MIL specification requirements of $150^{o}C$ (i.e., 85 + 65). Thus, while it appeared that an optical sensing system could be designed to operate at $150^{o}C$, no way could be devised to protect the sensors from the $200^{o}C$ soakback condition; particularly in a no-power situation. The maximum storage temperature of the optical sensors varies between $105^{o}C$ and $125^{o}C$.

Second phase gases in liquids have the effect of scattering away ambient light such as to significantly increase the attenuation of light transmitted through the fluid. Since jet engine lubricants carry significant and variable amounts of gas through the lube system, it would be desirable to design a sensing system that would not be affected by this phenomenon. Preliminary experiments were conducted to evaluate the feasibility of utilizing a reflected light scheme rather than the conventional transmitted light. The results showed that the concept was viable but that the system was still affected by second phase gases. However, with the use of a reference channel, it is felt that a satisfactory system could be designed.

The investigation of optical systems was curtailed at this point pending the results of the other concept analyses.

It appeared that a satisfactory optical sensor system would be complex at best, with some operational or installation restrictions to avoid damaging soakback effects.

2.2 Resistive

This concept involved making the wear debris a resistive component in an electronic circuit. An interdigital grid, essentially the same as that used in the capacitive sensor (see Appendix A) was to be used without the protective insulation layer. It was theorized that deposited debris would reduce the impedance of the grid in proportion to the quantity of debris. Unfortunately, it was found that the resistivity of the contact between the particles and the grid was very variable and non-repetitive. In some instances, one particle would reduce the grid resistivity from open circuit to 100 ohms, while on other occasions, complete particle average would only reduce the resistivity to 1000 ohms. This quality of data rendered the concept of no value, and the investigation was terminated.

2.3 Inductive

The proposal here was to precipitate the wear debris inside an inductive coil; the ferromagnetic debris would increase the inductance of the coil, thus enabling a quantitative measurement.

A coil was constructed that could indeed detect the presence of individual particles down to 1 milligram (∿500 μm). However, deposits of particles, individually less than 20 μm, that weighed 1 milligram or more, were apparently undetectable. While the difference in response between individual large particles and clusters of smaller particles was not clearly

understood, it was apparent that an inductive measurement of these smaller particles was not feasible.

2.4 Hall Effect Sensor

A Hall effect sensor is a solid-state device that detects the presence and strength of magnetic fields. The intent here was to use such a device to monitor the changes in the projected magnetic field of the precipitating magnets due to the precipitated debris. This idea did not proceed beyond the paper stage. It became clear that Hall effect crystals are subject to extreme temperature coefficients, and maximum temperature limitations. This renders the device of no value for gas turbine oriented components.

2.5 Capacitive

This proved to be the more fruitfull area of study, and a capacitive device was ultimately selected for field development.

Figures 1 and 2 in Appendix A show a schematic representation of the capacitor. It is a monoplanar capacitor, with the individual plates forming an interdigital pattern. The plates are insulated by a thin layer of high dielectric material such that the capacitor never becomes a resistor during the deposition of conductive debris. An important point to note is that the debris is not sensed due to a change in the capacitive dielectric as in conventional capacitive sensors. Since the majority of wear particles are electrically conductive, the effect is to modify the capacitors plate geometry.

3.0 INSTRUMENT DEVELOPMENT

The following basic guidelines were used in the development of the instrument:

- Since the application was airborne, the minimization of weight and space was a priority.

- The ability to obtain a reading from the instrument by the aircraft ground crew while in the power off mode was a requirement.

- For the engine mounted sensor, MIL-STD-810C was used as a design guide for environmental constraints.

- For the complete system, MIL-STD-461 was used as a design guide for susceptibility to electromagnetic interference.

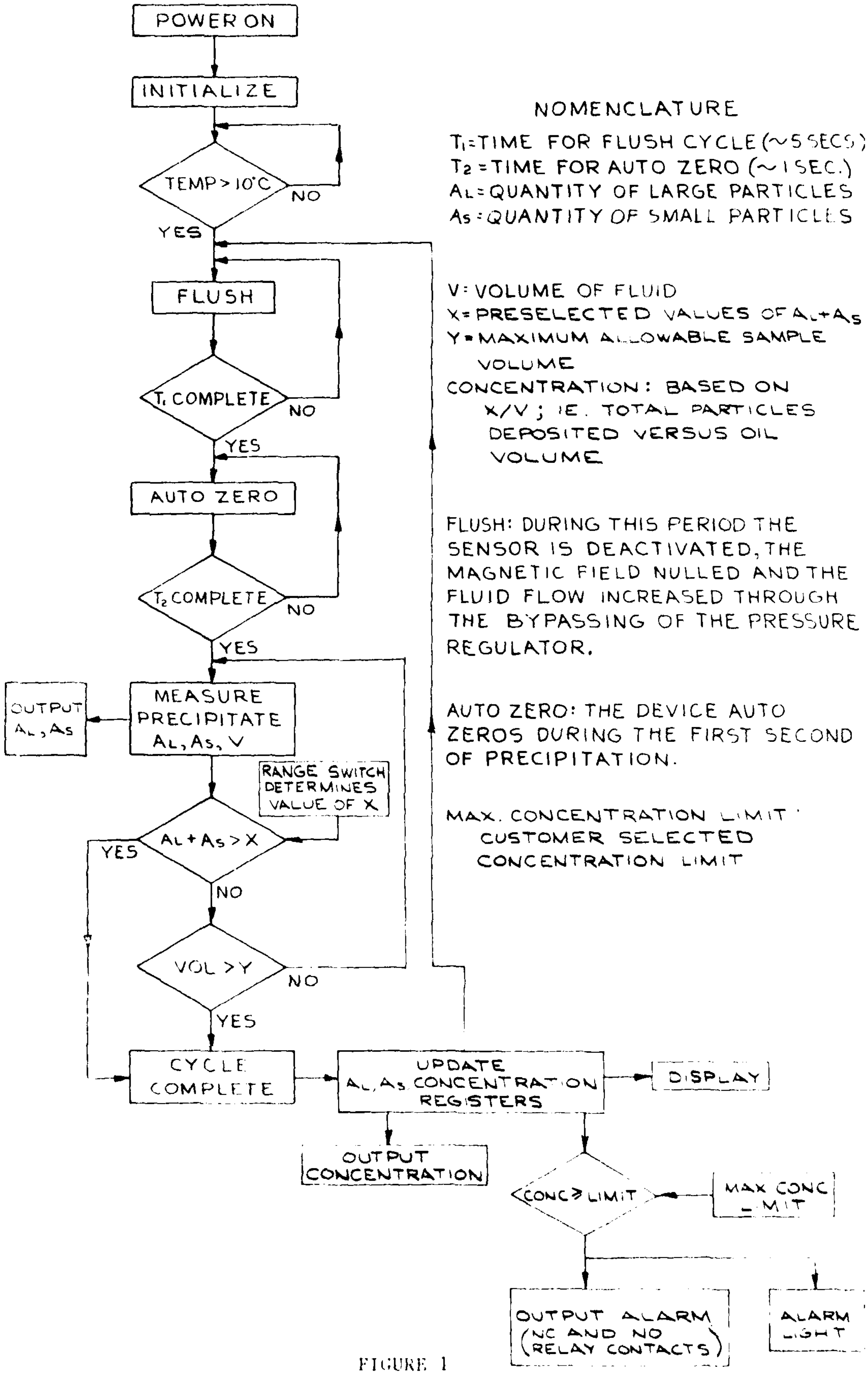
By its fundamental nature, the ferrographic separation demands that an on-line instrument be cyclical. That is, a particle separation and measurement phase must be undertaken and then followed by a recycling phase. This prerequisite of the design demands that both the electronics and mechanical package are considerably more sophisticated than a conventional passive instrument. The type of controls that are required are the ability to mechancially flush the sensing cell and electrically calibrate the electronics. Figure 1 displays the system logic diagram used in the final design. In addition to the above control functions, memory registers and high level alarm circuitry are included. The airborne version, the subject of this report, used electromechanical registers such that the ground crew could ascertain the last instrument reading prior to engine shutdown.

Figure 2 is a schematic diagram of the fluid logic circuit for the instrument sensors. The pressure regulator provides controlled flow during the precipitation cycle while the solenoid valve opens to enable the sensing cell to be flushed at the end of each cycle.

The following subsections will expand on pertinent individual components within the system.

ON-LINE FERROGRAPH LOGIC DIAGRAM

30 AUG 77
REV 6 OCT 78
REV 16 OCT 79



NOMENCLATURE

T_1 = TIME FOR FLUSH CYCLE (~5 SECS)
T_2 = TIME FOR AUTO ZERO (~1 SEC.)
A_L = QUANTITY OF LARGE PARTICLES
A_S = QUANTITY OF SMALL PARTICLES

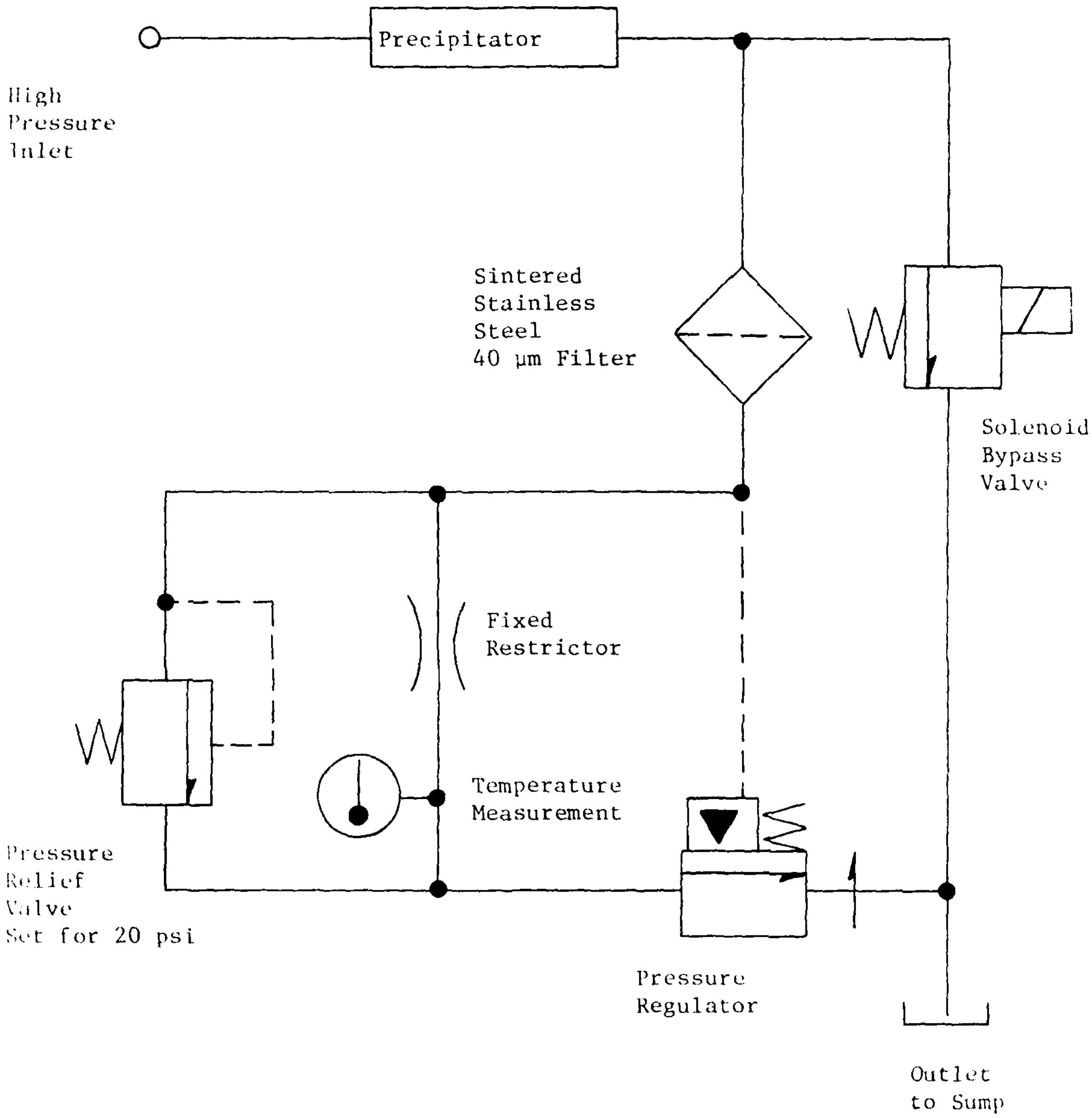
V = VOLUME OF FLUID
X = PRESELECTED VALUES OF $A_L + A_S$
Y = MAXIMUM ALLOWABLE SAMPLE VOLUME
CONCENTRATION: BASED ON X/V; IE. TOTAL PARTICLES DEPOSITED VERSUS OIL VOLUME

FLUSH: DURING THIS PERIOD THE SENSOR IS DEACTIVATED, THE MAGNETIC FIELD NULLED AND THE FLUID FLOW INCREASED THROUGH THE BYPASSING OF THE PRESSURE REGULATOR.

AUTO ZERO: THE DEVICE AUTO ZEROS DURING THE FIRST SECOND OF PRECIPITATION.

MAX. CONCENTRATION LIMIT: CUSTOMER SELECTED CONCENTRATION LIMIT

FIGURE 1



FLUID LOGIC CIRCUIT

FIGURE 2

3.1 Magnetic Circuit

Figure 3 shows the design of the precipitation magnet circuit along with the coils used to null the field during the flush cycle. This concept of magnet circuit design was found to be preferable to a conventional electromagnet for several reasons:

- The normal duty cycle for the magnetic field is typically 98 percent on, and 2 percent off. For an electromagnet, this is essentially continuous duty. Therefore, reversing the role of the electrical coils considerably reduces the power consumption.

- Having high power densities in the interconnecting cable during the short flush cycle does not impact the signal transmission during the precipitation cycle.

- Since the reverse mode has at most a 5 percent duty cycle, this enables a substantial lowering of the weight of coil copper.

It must be noted that it is the availability of samarium-cobalt alloy magnets that enables this concept to be practical. These magnets have a maximum operating temperature in excess of 200°C and fully recover from the imposed flux reversal during the flush cycle. Figure 4 displays the effectivity of the nulling coils as the current is increased. It can be seen that the flux density returns to the exact starting value once the nulling current is removed. Figure 5 relates the coil voltage, and thus temperature, to repetitive cycling. The worst case situation is selected, i.e., 16 percent duty cycle and 150°C ambient temperature. It can be seen that the maximum coil temperature stabilizes at 233°C which is within tolerable limits for class H magnet wire.

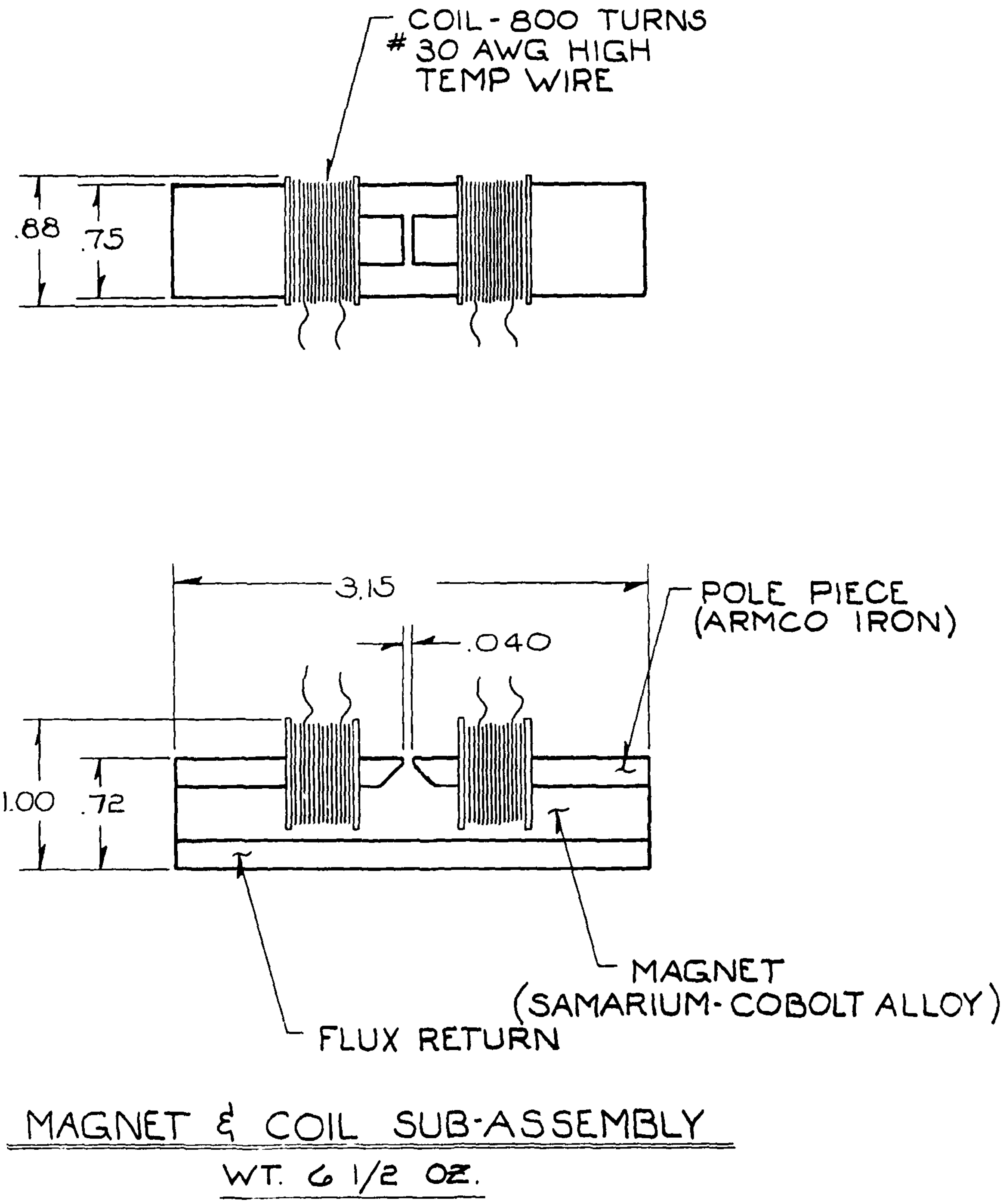
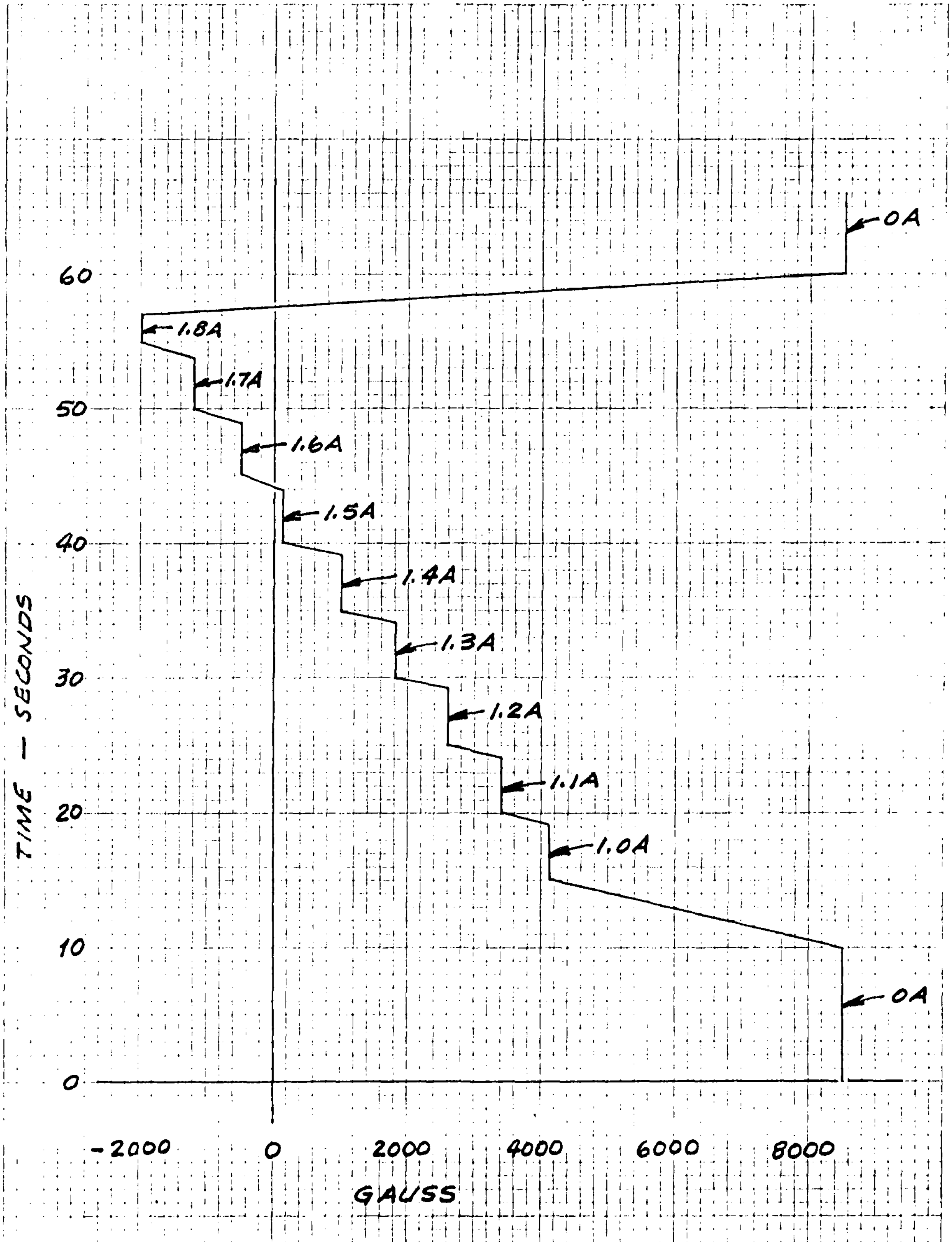

COIL - 800 TURNS
30 AWG HIGH
TEMP WIRE
.88
.75
3.15
.040
POLE PIECE
(ARMCO IRON)
1.00
.72
MAGNET
(SAMARIUM- COBOLT ALLOY)
FLUX RETURN
MAGNET & COIL SUB-ASSEMBLY
WT. 6 1/2 OZ.

FIGURE 3



EFFECT OF COIL CURRENT ON
FIELD STRENGTH
IN THE POLE PIECE GAP

FIGURE 4

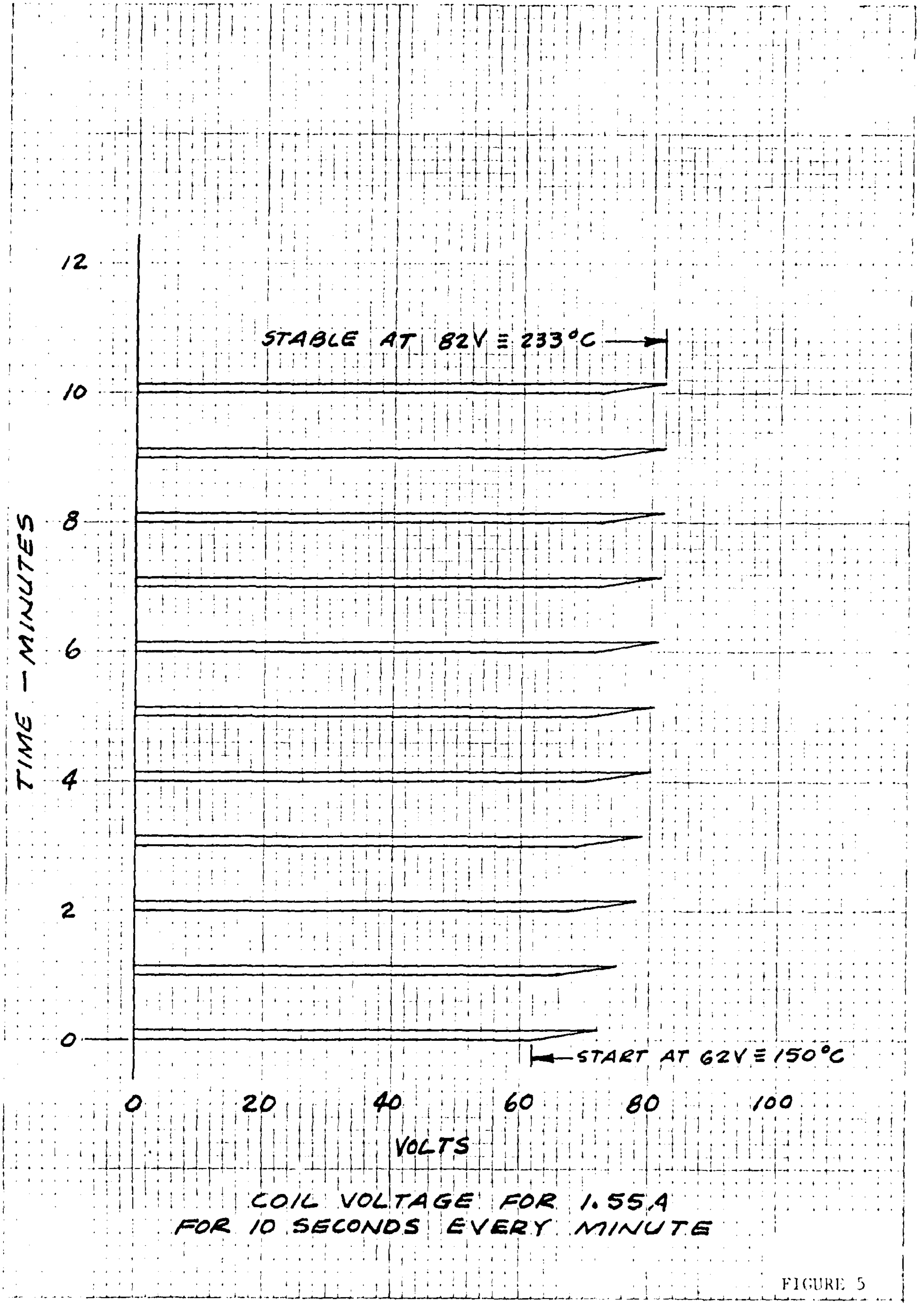

STABLE AT 82V ≡ 233°C
START AT 62V ≡ 150°C
TIME - MINUTES
0
2
4
6
8
10
12
0
20
40
60
80
100
VOLTS
COIL VOLTAGE FOR 1.55A
FOR 10 SECONDS EVERY MINUTE

FIGURE 5

3.2 Pressure Regulator

Since the sensing head is designed to be installed directly into the aircraft engine high pressure lube system, it must have some means of controlling the flow rate of lubricant. Figure 2 displays the fluid logic circuit of the sensing head. It consists of three primary components.

- The precipitator cell, which houses the capacitive sensor along with the magnet circuit described in the previous section.

- The pressure regulator, which controls the fluid flow during the precipitation cycle. This regulator must keep the flow rate constant at any given temperature regardless of the differential pressure across the sensing head. The pressure regulator achieved this by using the differential pressure across a fixed restrictor to move a bellows diaphragm and needle valve assembly, i.e., a single stage unbalanced regulator. The 20 psi pressure relief valve protects the bellows from overpressure due to startup surges or air entrainment surges. It should be noted that the fixed restrictor is of a friction type rather than an orifice. This is done to ensure that the flow characteristics of temperature match those of the precipitation cell. The relationship must be that the flow rate is proportional to the inverse of the viscosity. The temperature measurement at the restrictor enables the electronics to directly calculate the flow rate as a function of temperature and the known viscosity relationship with temperature for that oil.

- The final component is the solenoid valve. This valve will open during the flush portion of the instruments'

cycle and thus provides a bypass for the pressure regulator. This increase in flow rate simultaneous with the nulling of the magnetic field flushes all the debris out of the precipitation cell.

4.0 PRINCIPLE OF OPERATION

The on-line ferrograph is a cyclical device. It undertakes a measurement over a period of time that automatically varies from 30 seconds to 30 minutes, depending on debris concentration and operating temperature. At the end of each cycle, three parameters are measured:

- Large particle reading (L).
- Small particle reading (S).
- Total concentration of debris (C).

The units of large and small particle reading measurements are arbitrary; the relevance of the information being the deviation from pre-established norms for that lubricating system. The significance of the L and S readings may be interpreted as follows: if at cycle end S is equal to zero and L has a finite value, all the particles are greater than 5 μm in major dimension. If at cycle end L is equal to S, all particles are less than 2 μm in major dimension. Both of the above instances are the extremes of possible particle distributions; fluid systems normally operate between these two limits. The units of concentration are parts per million ferromagnetic or strongly paramagnetic debris within the fluid sample. The value of concentration is derived by relating the sum of large and small readings (L and S) to the volume of sample.

To undertake a debris concentration measurement, two individual parameters must be known; the quantity of debris and the volume of fluid from which the debris was extracted. Since the fluid pressure

is internally regulated, the flow rate of fluid through the sensor is a known function of temperature, thus volume of fluid is determined by a combined time and temperature measurement. The quantity of precipitated debris is determined by a capacitive measurement. Interdigital capacitors (see Appendix A) are placed above the magnet poles. The debris is deposited onto these grids which, in effect, increases their capacitance. The change in capacitance is converted to a voltage signal within the electronics package. Changes in fluid dielectric and zero drift are compensated by a reference grid and auto zero circuits. The dynamic concentration range of the instrument is 1 to 100 ppm. System linearity is maintained by measuring the volume of fluid required to precipitate a fixed quantity of debris. Consequently, it will be noticed that the sum of the large particle and small particle readings is always a constant on any one range. It is the difference between the two readings (L - S) that is indicative of the relative severity of the wear mode.

If the actual concentration of debris falls below 1.0 ppm, the instrument will revert to a secondary operating mode. Rather than perform a fixed quantity of debris measurement, the instrument will provide large and small particle readings based on a fixed volume of oil; the fixed volume of oil being 20 mls. In this event, the concentration readings will remain at 1.0 ppm.

The wear analyzer provides 0 - 10 VDC analog outputs proportional to each of the three measurements, i.e., wear particle concentration, large particles, and small particles.

5.0 CONCLUSIONS

The completely assembled system was extensively tested at Foxboro Trans-Sonics prior to shipment to Naval Air Propulsion Center, Trenton, New Jersey. It was found to be responsive to variations in particle concentration in the oil throughout the operating

temperature range (10 - 150°C) and differential pressure range (30 - 200 psi). The system has been tested according to the prescribed Military Specification and was found to be satisfactory. Testing included the vibration and ambient temperature portions of MIL-STD-810C for the sensor, and MIL-STD-461 (Items CS01, CS03, CS06, and radiated susceptibility to 5 V/m) for electromagnetic interference.

Testing was conducted using lubricating oil complying with MIL-L-23699. Free metal rubbing and severe sliding wear particles were used throughout the testing and development of the instrument. Since the capacitance sensor grids are spaced 6.25 μm apart, the instrument becomes progressively more sensitive to particles greater than that dimension. The sensor was, however, calibrated for particles in the size range 1 - 6 μm. The theoretical decrease in sensitivity below 6.25 μm is virtually eliminated in practice by the tendency of the magnetic separation to cause the particles to link together and form chains on the sensor surface.

Calibration of the instrument to particle concentration was achieved by cross correlation with the D.R. Ferrograph, Emmission Spectrometer, and a gravimetric mass measurement.

Figures 6 and 7 display dimensional prints of the sensor and electronics and the instrument specifications are presented in Appendix B. These specifications include operating condition and instrument performance at those conditions.

Since the original shipment (1978), extensive development work has been continued on a land-based system (using internal funds). The current state of the product shows significant improvement in accuracy and capability that reflects this effort. Specifically, the improvements are as follows:

a) Accuracy has been improved by approximately 40%.

b) The large and small particle data has been manipulated to provide a reading proportional to the percentage of large particles present.

c) Both the concentration and percent large analog outputs are latched at the previous completed cycle value. This provides continuous rather than intermittent data.

d) An adjustable high concentration alarm module has been incorporated into the instrument.

It is hoped that this newer technology may be applied to different Military programs in the future.

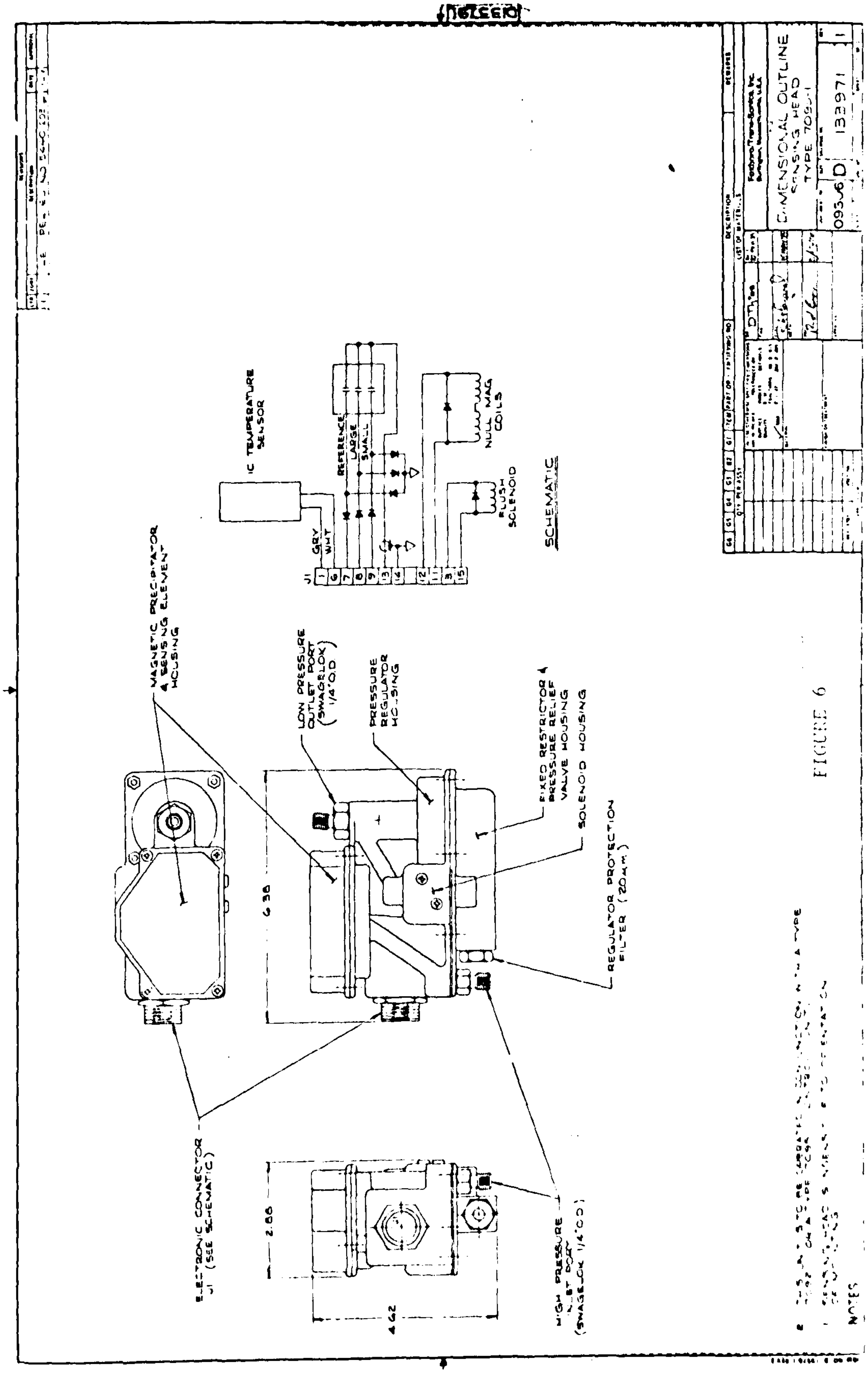
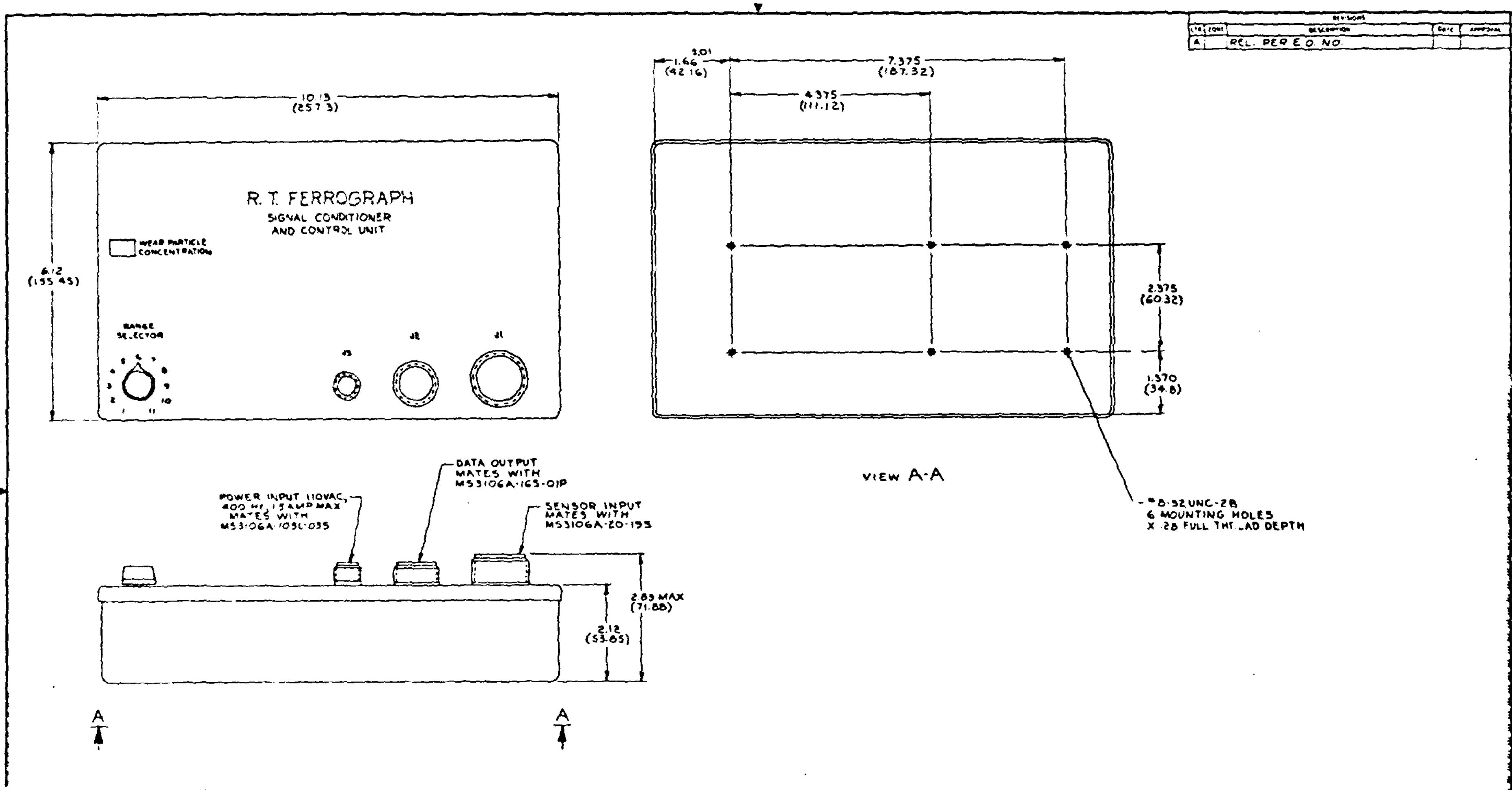

MAGNETIC PRECIPITATOR & SENSING ELEMENT HOUSING
LOW PRESSURE OUTLET PORT (SWAGELOK) 1/4 O.D
PRESSURE REGULATOR HOUSING
FIXED RESTRICTOR & PRESSURE RELIEF VALVE HOUSING
SOLENOID HOUSING
REGULATOR PROTECTION FILTER (20μm)
6.38
ELECTRONIC CONNECTOR J1 (SEE SCHEMATIC)
HIGH PRESSURE INLET PORT (SWAGELOK 1/4 O.D)
2.88
4.62
IC TEMPERATURE SENSOR
J1
GRY
WHT
REFERENCE
LARGE
SMALL
NULL MAG COILS
FLUSH SOLENOID
SCHEMATIC
NOTES
DIMENSIONAL OUTLINE
SENSING HEAD
09356
D
133971

FIGURE 6



3. FINISH: PAINT FOXCO GREEN #58.
2. MATERIAL: 16 GAUGE (.090) ALUM
1. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES (MILLIMETERS REFERENCED).

NOTES

SEE NOTE 2

SEE NOTE 3

Foxboro/Trans-Sonics, Inc.

DIMENSIONAL OUTLINE
SIGNAL CONDITIONER CONT. UNIT
TYPE 7092-1

09306 | D | 133772 | A

FIGURE 7

APPENDIX A

Entry Number, Do not fill in

IDEA DISCLOSURE

TITLE OF IDEA.......A Single Plane Capacitive Sensor

ORIGINATOR(S).......E. Roderic Bowen, Robert A. Hazard ....DEPT.......084

FIELD OF IDEA.......The Capacitive Sensing of Fluids or Particles at a Solid/Fluid Interface

SKETCH AND DESCRIPTION (EMPHASIZE NOVEL FEATURES AND BENEFITS)
(STATE WHAT NEED IT SATISFIES)

PLEASE USE INK
Use reverse side of this sheet or attach additional sheets as required

This disclosure discusses the development of a capacitive sensor at Foxboro/Trans-Sonics,Inc. during the period 1 September 1976 to the present.

PATENT SUBJECT: The capacitive sensing of fluids or particles at a solid/fluid interface. Any particles being part of a fluid medium may themselves be solids or second-phase fluids.

As with all capacitive sensing techniques, use is made of either the conductivity or different dielectric constant of the fluid or particles as compared with the dielectric constant of a reference medium. Conventionally, it is the change in electric field between the capacitive plates due to fluid or particulate presence between the plates that constitutes the sensing technique. In the current design, however, the capacitor constitutes one solid/fluid interface only; both capacitor plates being part of a single plane solid surface. Hence, *particulate sensing* is conducted outside the capacitor plate edges rather than between the plates.

Figure 1 displays two conceptual designs, both of which have been evaluated and proved successful in detecting the presence of second-phase water in oil, metallic particles in oil, and changes in dielectric of the fluid medium.

Figures 2 and 3 are detailed designs of sensors based on the concepts of Figure 1 which [illegible] manufacture and testing of have confirmed the device's capability. If the device is used to detect the presence of second-phase particles in the fluid, the sensor's [illegible]ility may be enhanced by prior separation of the particles onto the sensor surface. [illegible] separation may be achieved gravimetrically, magnetically, etc. Any prior separation if used need not be a part of this patent.

[illegible] should be noted that a design feature that has enabled the practical application [illegible] concept is the ability to produce extremely narrow metallic lines (approximately [illegible] meters wide). Consequently, one can generate sufficient capacitance in a [illegible] area to make a practical measurement feasible. For instance, the individual [illegible] millimeter sensing pads in Figure 3 (part-P1) will have a capacitance of [illegible]ately 30 picofarads in air (dielectric-1) and approximately 60 picofarads in [illegible]ethylene (dielectric-9).

SIGNATURE(S) E. Roderic Bowen, Robert A. Hazard ....DATE.......1 Sept 1978

WITNESS: READ AND UNDERSTOOD: Paul A. Davis ....DATE.......1 Sept 1978

([illegible]) SHEETS ATTACHED

INITIAL AND DATE EACH SHEET

SEND TO DEPT 187

Foxboro

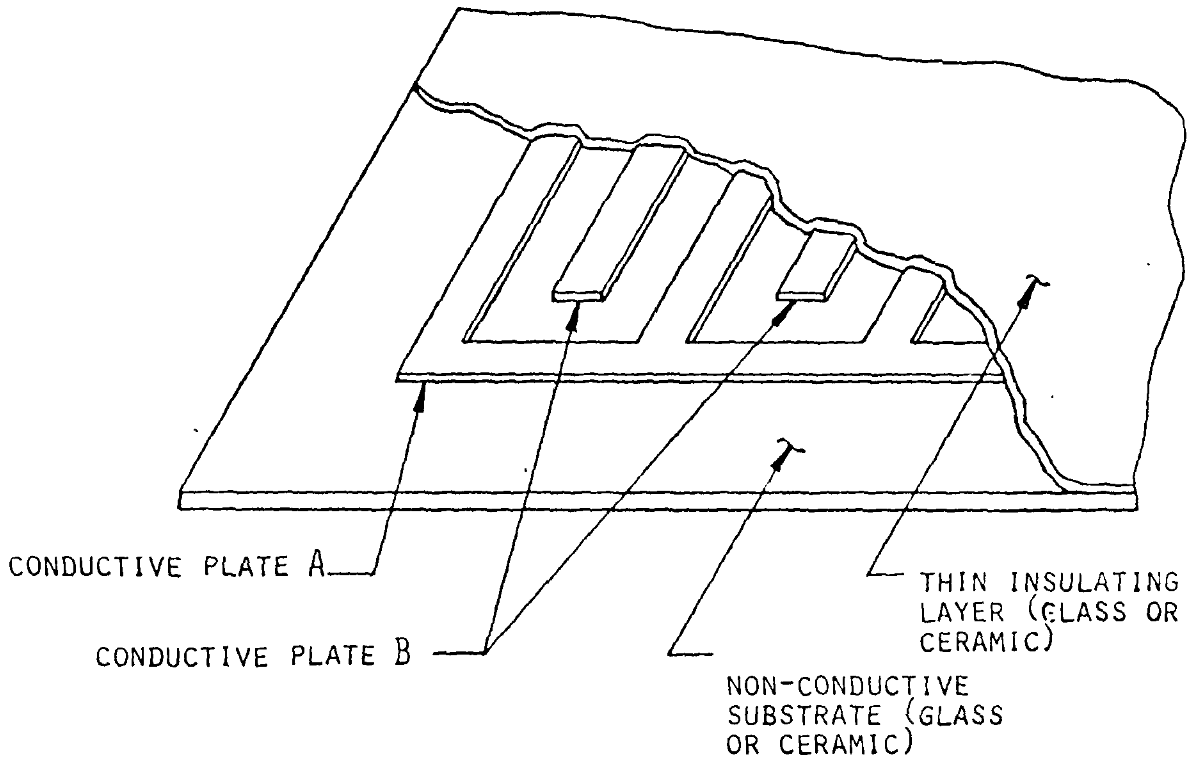


FIGURE 1A

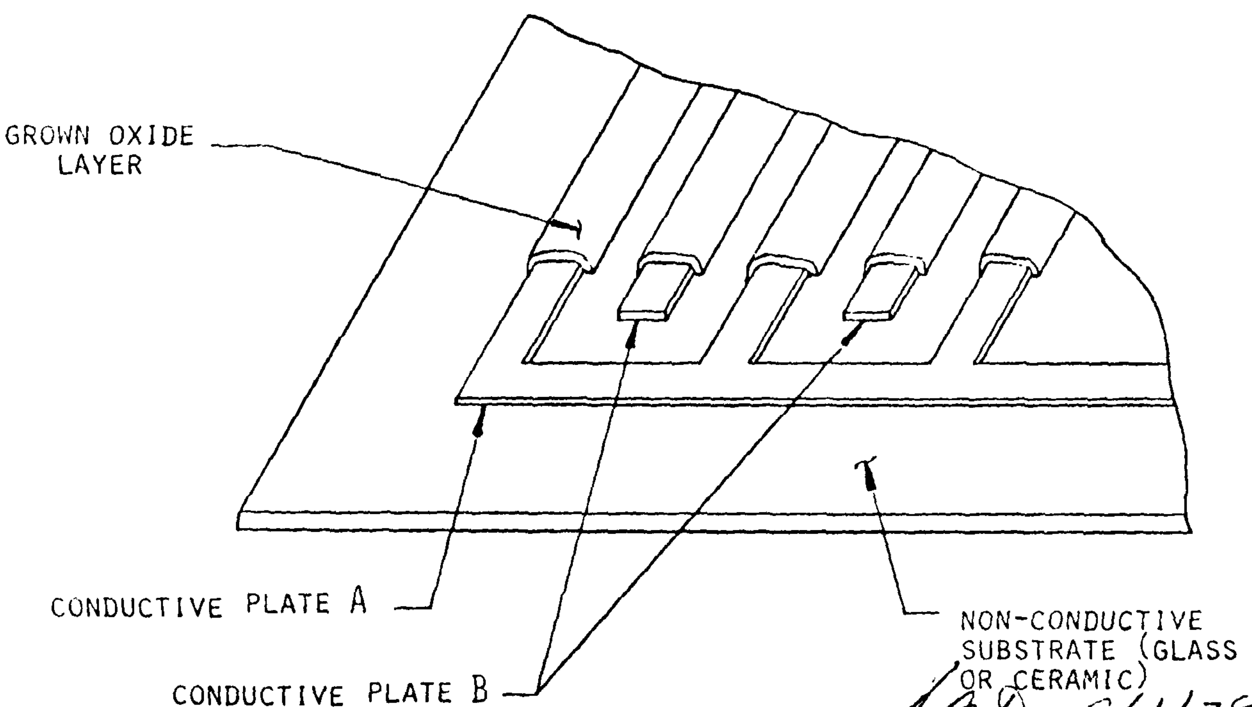
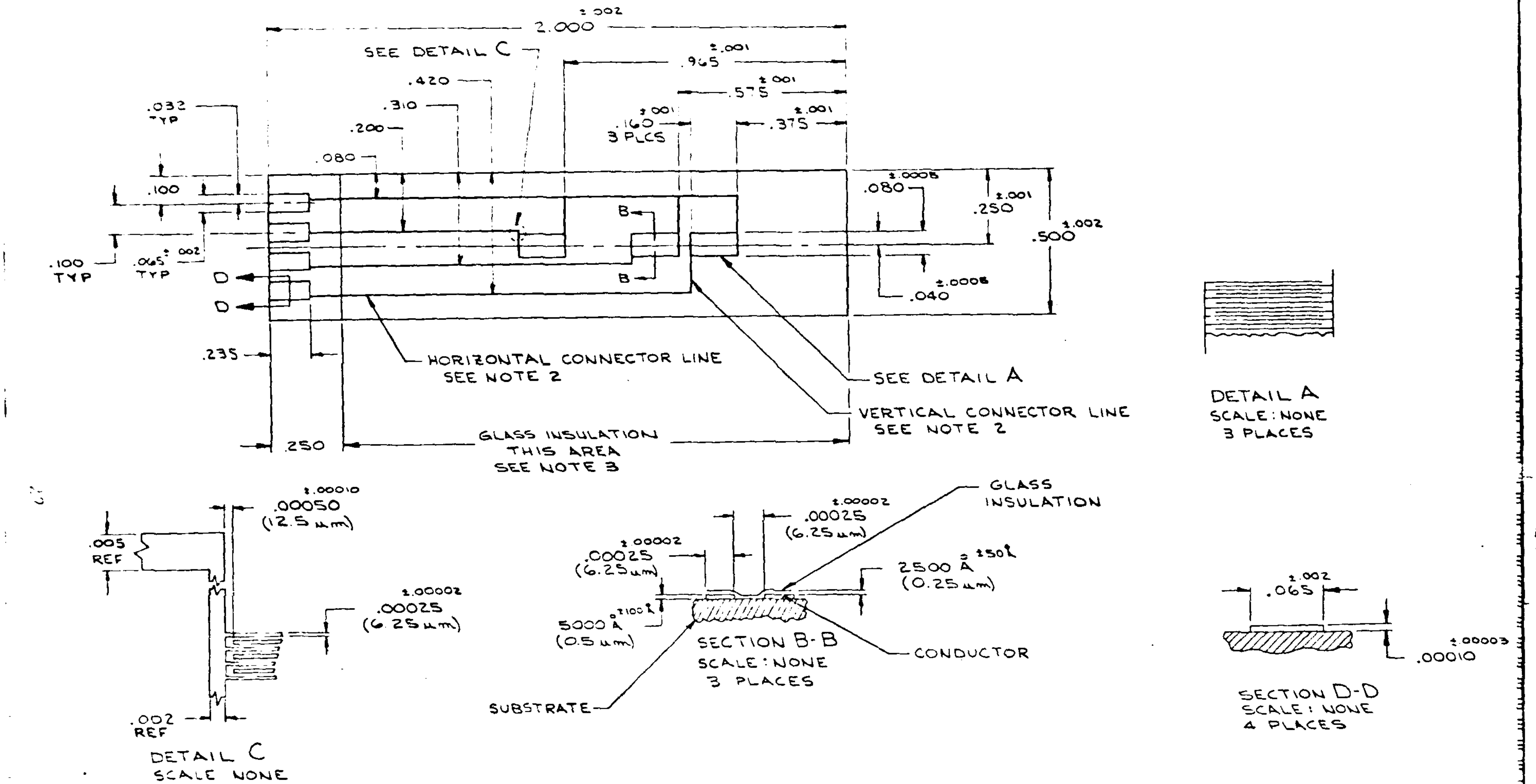


FIGURE 1B

9/1/78
E.R.B. 9/1/78
R.A.H. 9/1/78

ZONE	REV	DESCRIPTION	DATE	APPROVED
B		REV PER EO NO 5447-122		



3 GLASS INSULATION SHALL BE CONFINED TO THE AREA SHOWN.

2 ALL HORIZONTAL CONNECTOR LINES .005 WIDE
ALL VERTICAL CONNECTOR LINES .002 WIDE

MATERIAL:
SUBSTRATE MATERIAL: .020 CORNING 7059 GLASS
CONDUCTOR MATERIAL: GOLD

NOTES

G6	G5	G4	G3	G2	G1	ITEM	PART OR IDENTIFYING NO	DESCRIPTION	REMARKS
QTY PER ASSY								LIST OF MATERIALS	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON: ANGLES ± 30' FRACTIONS ± 1/32 DECIMALS XX ± .015 XXX ± .005
SURFACE QUALITY √ MAX

MATERIAL: SEE NOTE 1

FINISH OR TREATMENT

DR: W. D. Connell DATE 12/8/76

CHK

ELEC

MECH

PROJ

APPROVAL

Foxboro/Trans-Sonics, Inc.
Burlington, Massachusetts, U.S.A.

TITLE
R.T. FERROGRAPH
CAPACITIVE SENSOR

CODE IDENT NO	SIZE	DRAWING NO	REV
09306	C	133370	B

SCALE | UNIT WT | SHEET 1 OF 1

APPENDIX B

AIRBORNE ON LINE FERROGRAPH

SPECIFICATION DATA SHEET

ELECTRONIC

Power Input: Connector MS3106A 10SL-3S(C), 115 VAC, 400 Hz, per MIL-S-708

Max VA - 180 (during 5 second flush cycle)

Output Signals: Connector MS3106A 16S-1P

Large Particle Reading	0 - 10 VDC
Small Particle Reading	0 - 10 VDC
K/V (Wear Particle Concentration)	0 - 10 VDC

V = Sample Volume

Y = Maximum Permissible Value of V

K = Constant (for 0 - 100 Scale Output)

End of Cycle Signal: Open Collector Transistor

Display: Two Digit Mechanical - K/V (Last Full Cycle)

Range Switch: 10 position

Varies Y (Maximum Permissible Value of V)

1 position $y = \infty$

Relationship Between Range Positions:

$$P(n+1) = 50 + 0(n)$$

or

$$Q(n) = 2 \cdot P(n+1) - 100$$

where

$$Q(n) = K/V \text{ @ Range } n$$

and

$$P(n+1) = K/V \text{ @ Range } n+1$$

MECHANICAL

Required Oil Pressure: 30 - 200 psi

Inlet Port: Swagelok 1/4" (O.D.) tube fitting (P/N SS-400-1-4ST)

Outlet Port: Swagelok 1/4" (O.D.) tube fitting (P/N SS-400-1-8ST)

Dimensions: 7091-1 Sensing Head
Envelope Dimensions: 2.75" x 5.63" x 4.5"
Weight: 2-1/2 lbs.

7092-1 Electronics Package
Envelope Dimensions: 10" x 6" x 2"
Weight: 2 lbs

Interconnection Cable
Length: 25 feet

FOXBORO

OPERATING CONDITIONS

These conditions will be tabulated separately for sensor with cable and the wear analyzer.

SENSOR (7093-1):

Influence	Normal Operating Conditions	Operative Limits	Storage & Transport Limits
Position	Insensitive to Orientation		
Ambient Temperature	0 to 150°C	-40 to 150°C	-40 to 200°C
Sample Fluid Temperature	10 to 150°C[1]	-40 to 150°C	N/A
Relative Humidity	0 to 100%	0 to 100%	0 to 100%
Sample Fluid Viscosity	2.5 to 100 Cs	N/A	N/A
Sample Fluid	MIL-L-23699 MIL-L-5606 SAE type oils	N/A	N/A
Sample Fluid Dielectric	2 to 4	N/A	N/A
Ambient Pressure	0 to 200 KPa	0 to 200 KPa	0 to 200 KPa
Sample Fluid Pressure Differential	250 to 1300 KPa	0 to 1400 KPa	N/A
Maximum Fluid Pressure	1400 KPa	1400 KPa	N/A
Electromagnetic Interference: Radiated susceptibility @ 27 - 512 MHz	5 V/m max.	20 V/m max.	N/A
Vibration	MIL-STD-810C Cat.b.1/F,L	MIL-STD-810C Cat.b.1/F,L	N/A

(1) These temperatures are related to the sample fluid viscosity; that is, the temperature range may be limited by viscosity considerations.

WEAR ANALYZER (7092-1):

Influence	Normal Operating Conditions	Operative Limits	Storage & Transport Limits
Ambient Temperature	-40 to 50°C	-40 to 55°C	-40 to 85°C
Relative Humidity	0 to 95%	0 to 100% no condensate	0 to 100% no condensate
Ambient Pressure	0 to 110 KPa	0 to 110 KPa	0 to 110 KPa
Environmental Contaminants	CES 278 Class B		
Supply Voltage	Rated ±10%	Rated ±10%	N/A
Supply Frequency	Rated ±5%	0 to 450 Hz	N/A
Output Load (0 to 10 VDC)	5K Ω min	2K Ω min	N/A
Electromagnetic Interference:			
a) Radiated Susceptibility (27-512 MHz)	5 V/m max	20 V/m max	N/A
b) Conducted Susceptibility (power line):			
MIL-STD-461/CS01 30 Hz to 50 KHz	3 volts rms	3 volts rms	N/A
MIL-STD-461/CS03 50 KHz to 400 MHz	1 volt rms	1 volt rms	N/A
MIL-STD-461/CS06 spike voltage	100 volts	100 volts	N/A
Vibration	CES 278 Level II		

PERFORMANCE SPECIFICATIONS

The primary measurement undertaken by the instrument is the concentration of wear debris in a fluid system. The units of concentration may be defined as parts per million (gravimetric) of ferromagnetic (or strongly paramagnetic) debris in the fluid; the size range of the measurable debris being 0.5 μm to 250 μm in major dimension.

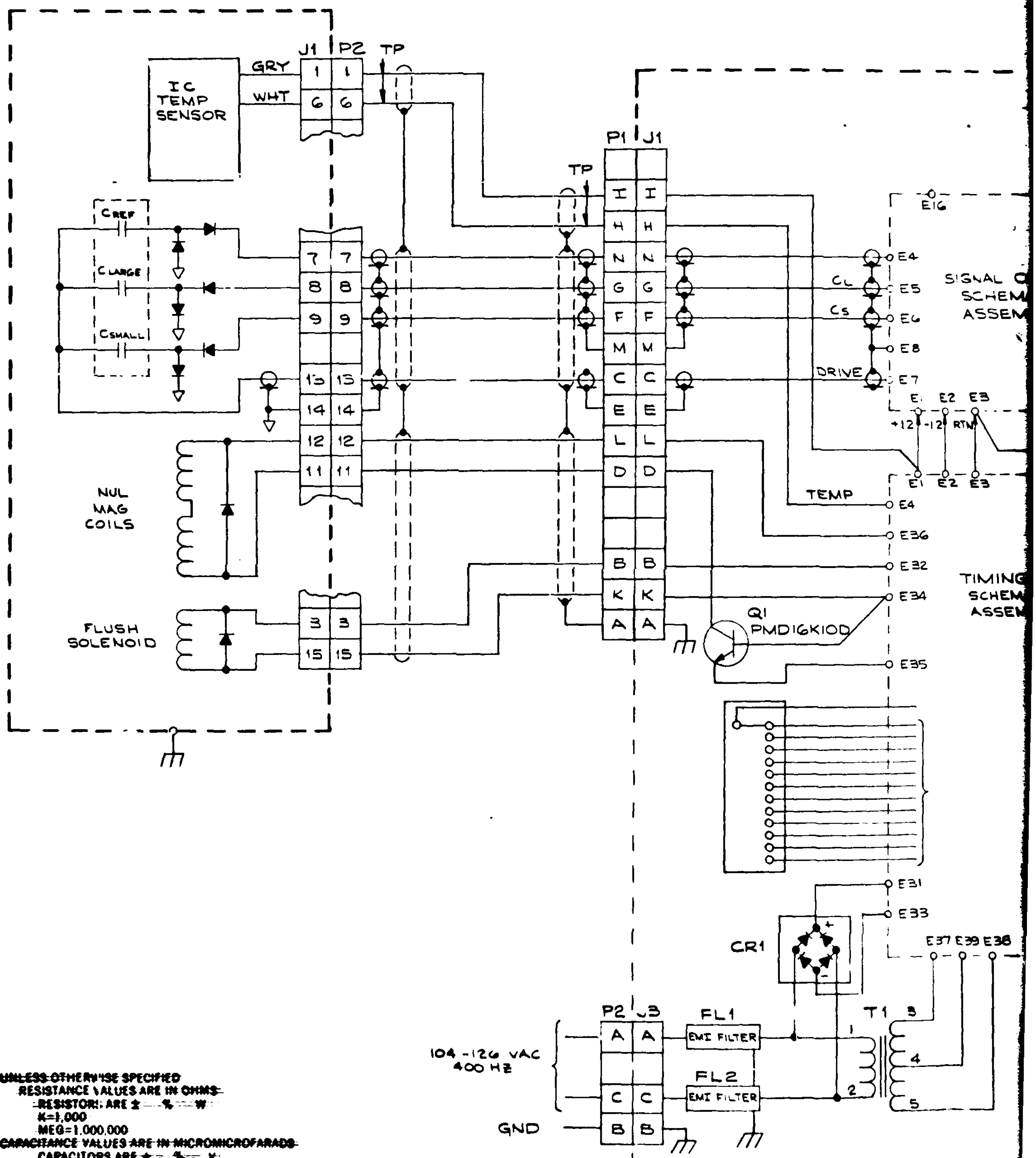
The system life expectancy is 100,000 hours minimum, with a 30,000 mean time between failure (M.T.B.F.).

Tabulated on the next page are required performance specifications with regard to the actual measurements. The following section tabulates the actual reference and operating conditions. Apply the greater of ppm of % of reading in the Table (see next page).

CONCENTRATION

Function		Operating
a)	Range (ppm)	1 to 100 ppm
b)	Resolution	1 ppm display 0.1 ppm (10 MV) analog output
c)	Accuracy	±0.5 ppm or ±15% of reading
d)	Repeatability at Fixed Concentration	0.5 ppm or 10% of reading, bandwidth

For (b), (c) and (d) above, the analog electrical output is 100 mV per 1 ppm.



~~1. UNLESS OTHERWISE SPECIFIED~~

~~RESISTANCE VALUES ARE IN OHMS~~

~~RESISTORS ARE ± — % — W~~

~~K=1,000~~

MEG=1,000,000

~~CAPACITANCE VALUES ARE IN MICROMICROFARADS~~

~~CAPACITORS ARE ± — % — V~~

~~UF=MICROFARADS~~

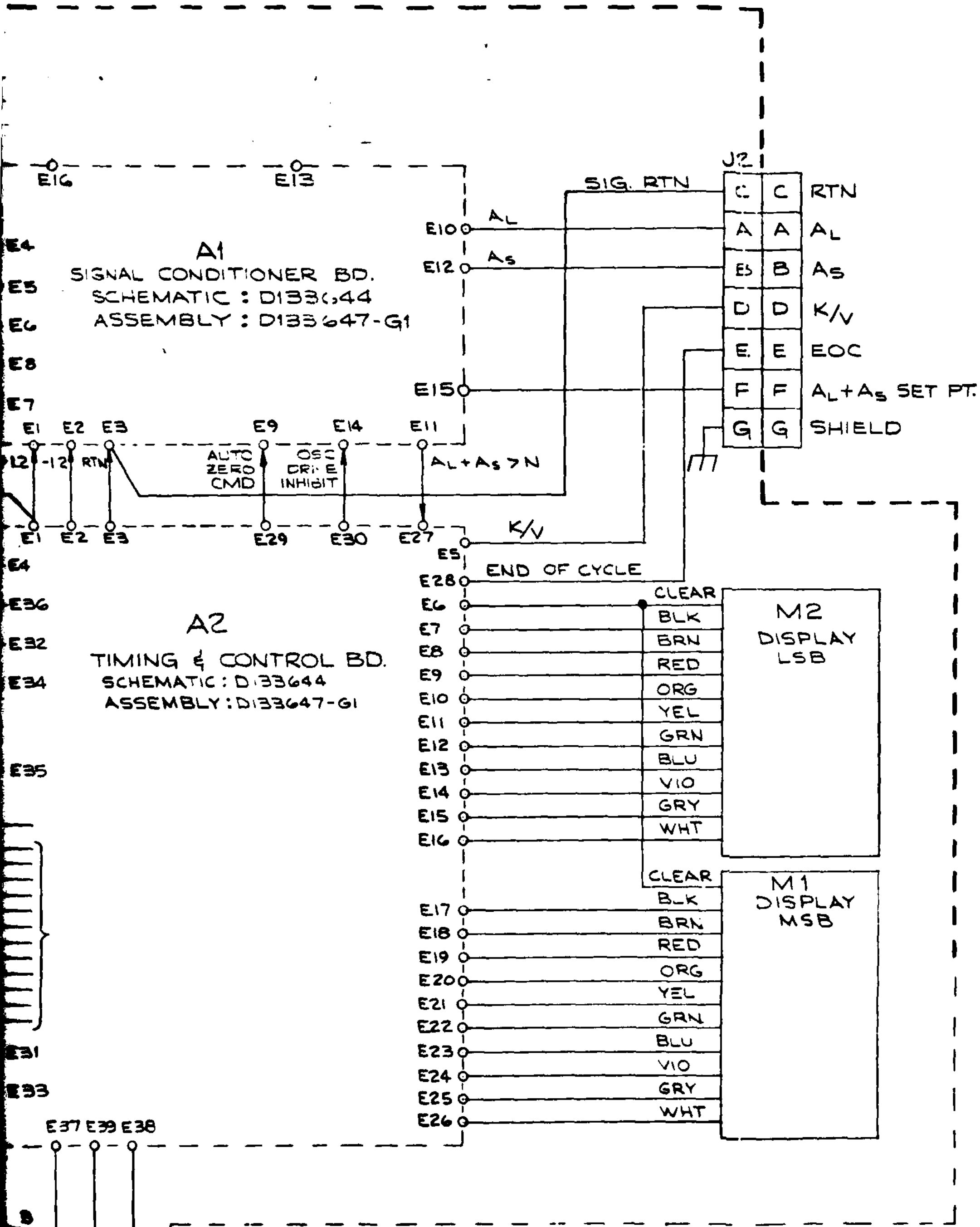
~~INDUCTANCE VALUES ARE IN MICROHENRIES~~

~~NOTES~~

PRELIMINARY

SUBJECT TO CHANGE WITHOUT NOTICE

REVISIONS				
LTR	ZONE	DESCRIPTION	DATE	APPROVAL
1		REL PER E.O. NO. 5440-203		



REFERENCE DATA		
DESCRIPTION	LAST NO.	DELETED NOS
RESISTOR		
CAPACITOR		
DIODE		
TRANSISTOR		
INDUCTOR		

WIRE RUN LIST

WIRING DIAGRAM

WIRING HARNESS

NEXT ASSY	USED ON
APPLICATION	

DR: W. O'Connell — DATE: 1 JUL 77

CHK

ENG

MFG

APPROVAL

TRANS-SONICS INC.

TITLE: INTERCONNECTION DIAGRAM KT FERROGRAPH

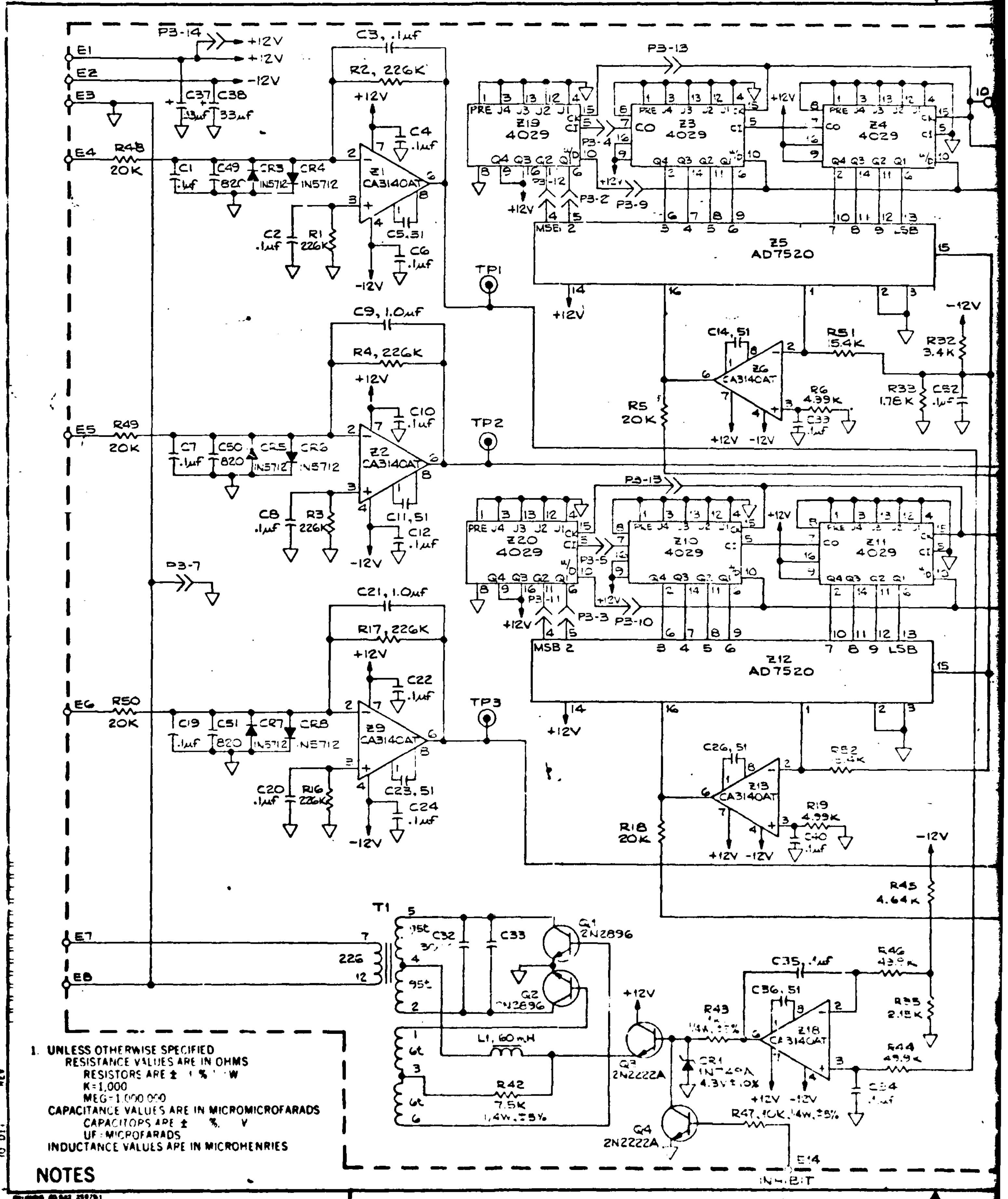
CODE IDENT NO	SIZE	DRAWING NO	REV
09306	D	133784	1

SCALE | UNIT WT | SHEET 1 OF 1

PRELIMINARY
SUBJECT TO CHANGE WITHOUT NOTICE

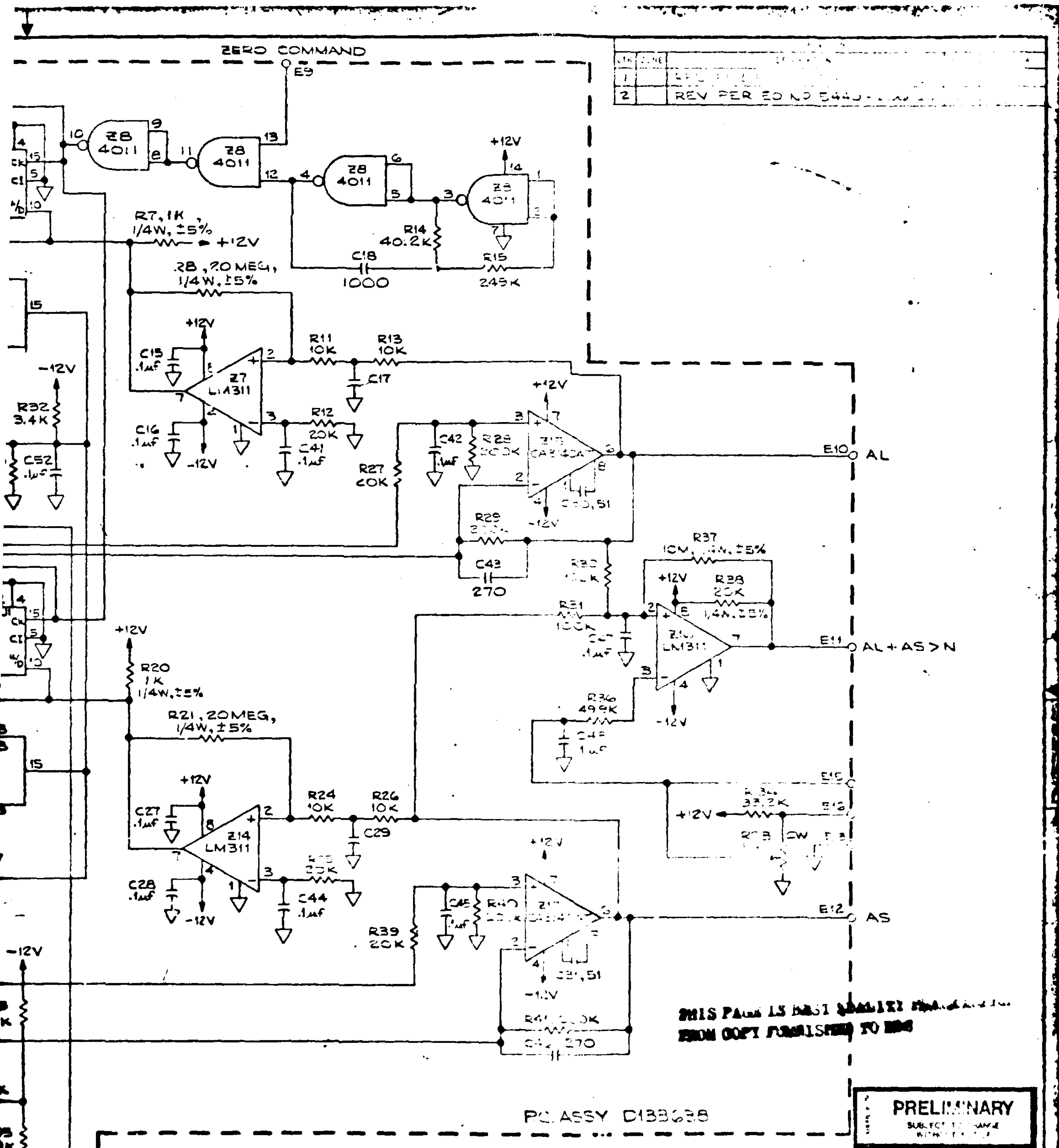
D133784

2



1. UNLESS OTHERWISE SPECIFIED
   RESISTANCE VALUES ARE IN OHMS
   RESISTORS ARE ± 1 % W
   K=1,000
   MEG=1,000,000
   CAPACITANCE VALUES ARE IN MICROMICROFARADS
   CAPACITORS ARE ± %, V
   UF=MICROFARADS
   INDUCTANCE VALUES ARE IN MICROHENRIES

NOTES



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PRELIMINARY SUBJECT TO CHANGE WITHOUT NOTICE

REFERENCE DATA		
DESCRIPTION	LAST NO.	DELETED NOS
RESISTOR	R58	
CAPACITOR	C52	C13, C25
DIODE	CR9	
TRANSISTOR	Q3	
INDUCTOR	L1	
I.C.	Z20	

WIRE RUN LIST

WIRING DIAGRAM

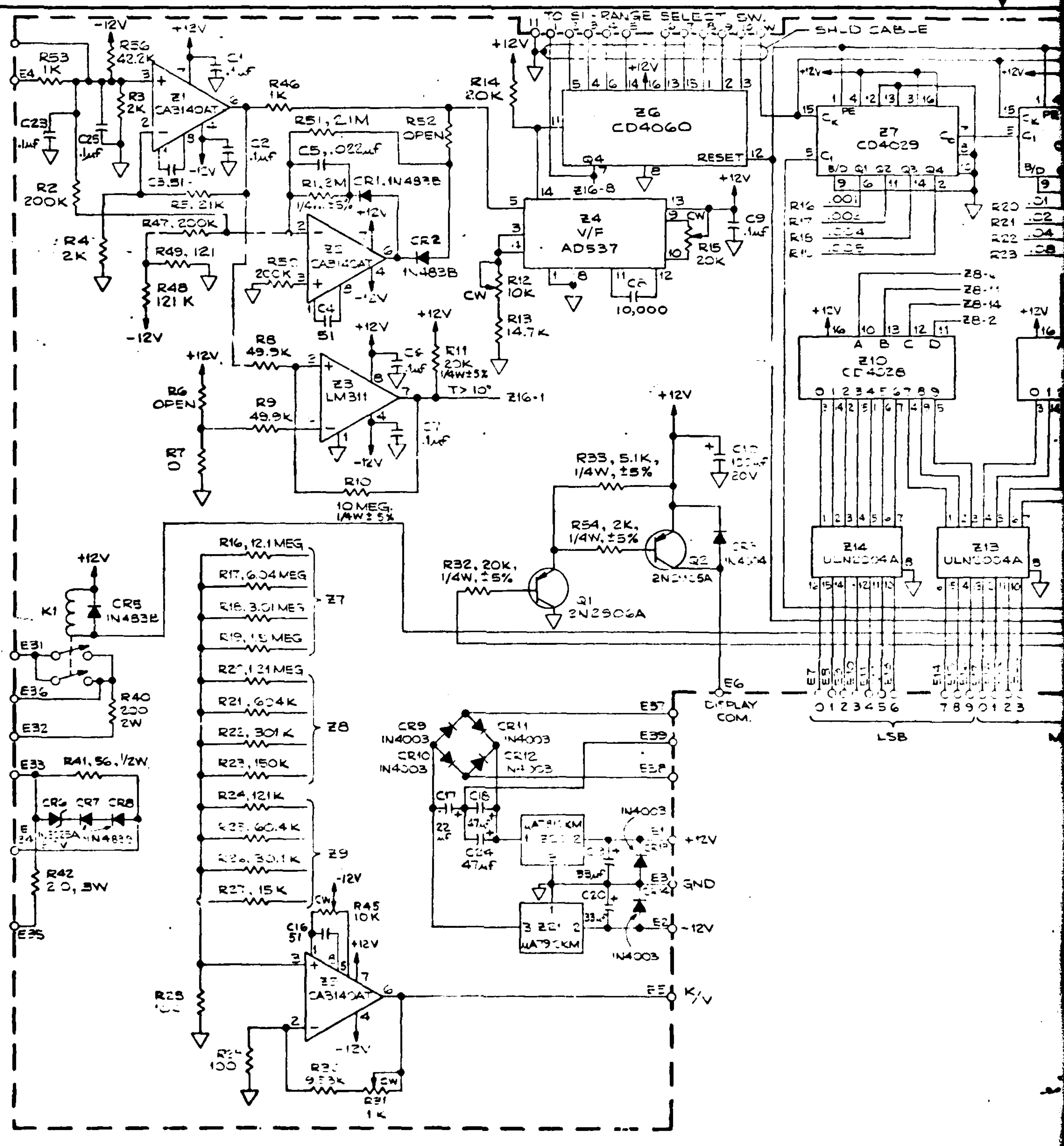
WIRING HARNESS

NEXT ASSY

Foxboro Trans-Sonics, Inc.
Burlington, Massachusetts, U.S.A.

SCHEMATIC DIAGRAM

09306 D

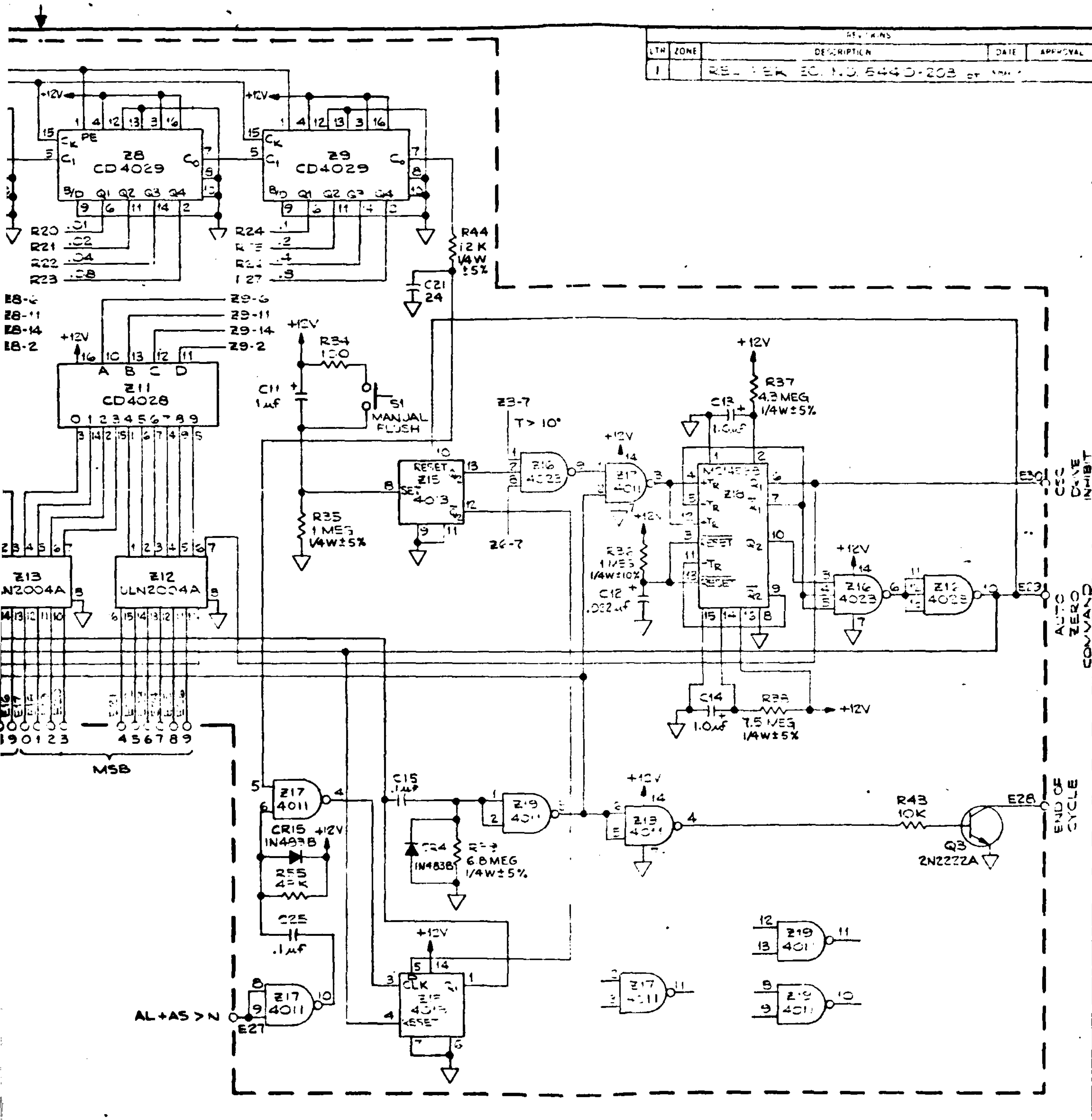


1. UNLESS OTHERWISE SPECIFIED
   RESISTANCE VALUES ARE IN OHMS
   RESISTORS ARE ± 1 % 1/10W
   K=1,000
   MEG=1,000,000
   CAPACITANCE VALUES ARE IN MICROMICROFARADS
   CAPACITORS ARE ± %, V
   UF=MICROFARADS
   INDUCTANCE VALUES ARE IN MICROHENRIES

NOTES

PRELIMINARY
SUBJECT TO CHANGE WITHOUT NOTICE

LTR	ZONE	DESCRIPTION	DATE	APPROVAL
1		REL PER EC. N.O. 5440-203		



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REFERENCE DATA		
DESCRIPTION	LAST NO	DELETED NOS
RESISTOR		
CAPACITOR	C25	
DIODE		
TRANSISTOR		
INDUCTOR		

WIRE RUN LIST

WIRING DIAGRAM

WIRING HARNESS

NEXT ASSY | USED ON

APPLICATION

PRELIMINARY
SUBJECT TO CHANGE WITHOUT NOTICE

Foxboro/Trans-Sonics, Inc.
Burlington, Massachusetts, U.S.A.

SCHEMATIC DIAGRAM
TIMING & CONTROL

09306 D

REV 1